History of the Vegetation at Burraga Swamp, Barrington Tops National Park, Upper Hunter River Region, New South Wales

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Burraga Swamp is set in a small enclosed basin in temperate *Nothofagus* rainforest with areas of eucalypt forests nearby and subtropical rainforest along the watercourses. The swamp sediments consist of 3.35 m of lake clay overlain by 2.65 m of peat. The base of the peat has been dated at 6,500 years and the base of the clay is possibly about 12,000 years B.P.

The vegetation was open and grassy, with few trees, until 6,500 years B.P., during the lake phase, and the lake supported periodic blooms of *Myriophyllum*. Towards the top of the lake phase, *Dicksonia* became common. The transition from a lake to a peat swamp was accompanied by an increase in *Nothofagus* pollen and temperate rainforests occupied the site from about 6,000 years B.P. to the present. Eucalypts remained relatively low throughout the whole of the time, hence eucalypt forests were only a minor component of the vegetation at the site. Woody myrtaceous swamp shrubs, e.g. *Leptospermum*, were sometimes abundant over the swamp.

The history of the vegetation at Burraga shows similar trends to those of other sites on the Barrington Tops studied by Dodson and colleagues. The *Nothofagus* forests expanded westwards about 6,000 years B.P., when the climate was slightly warmer and wetter, and there has been only minor variation since.

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INTRODUCTION

The Barrington Tops is an isolated plateau 1,000 to 1,500 m ASL in the Eastern Highlands (Fig. 1). Burraga Swamp is set in a small enclosed basin located at 985 m, below the plateau surface on the Mount Allyn Range, one of ridges leading up to the southern scarp of the plateau. The swamp is surrounded by temperate rainforest with *Nothofagus moorei* dominant, but there are areas of *Eucalyptus* forests close by and subtropical mixed rainforest on the protected slopes and in the gullies. With three major types of vegetation close by, any changes in distribution should be recorded in the swamp sediments.

Dodson and co-workers studied mire development and have reconstructed the vegetation history of a number of swamps from the plateau above 1,000 m (Dodson et al. 1986, Dodson 1987, see Fig. 2). Dodson et al. (1994) have also studied 2 cores from Burraga Swamp with a maximum depth of 35 cm and a maximum age of 2,140 years B.P. to assess the human impact on the palaeoenvironment. Dodson and Myers (1986) studied the modern pollen rain of the Barrington Tops and Upper Hunter River regions to define the pollen signature of the different types of vegetation. This latter study, together with other similar studies (e.g. Dodson 1983), show that most Australian pollen types travel in quantity only a few tens of metres from their source. Swamp sediments are thus likely to record a predominantly local history of the vegetation. This study of a 6 m core

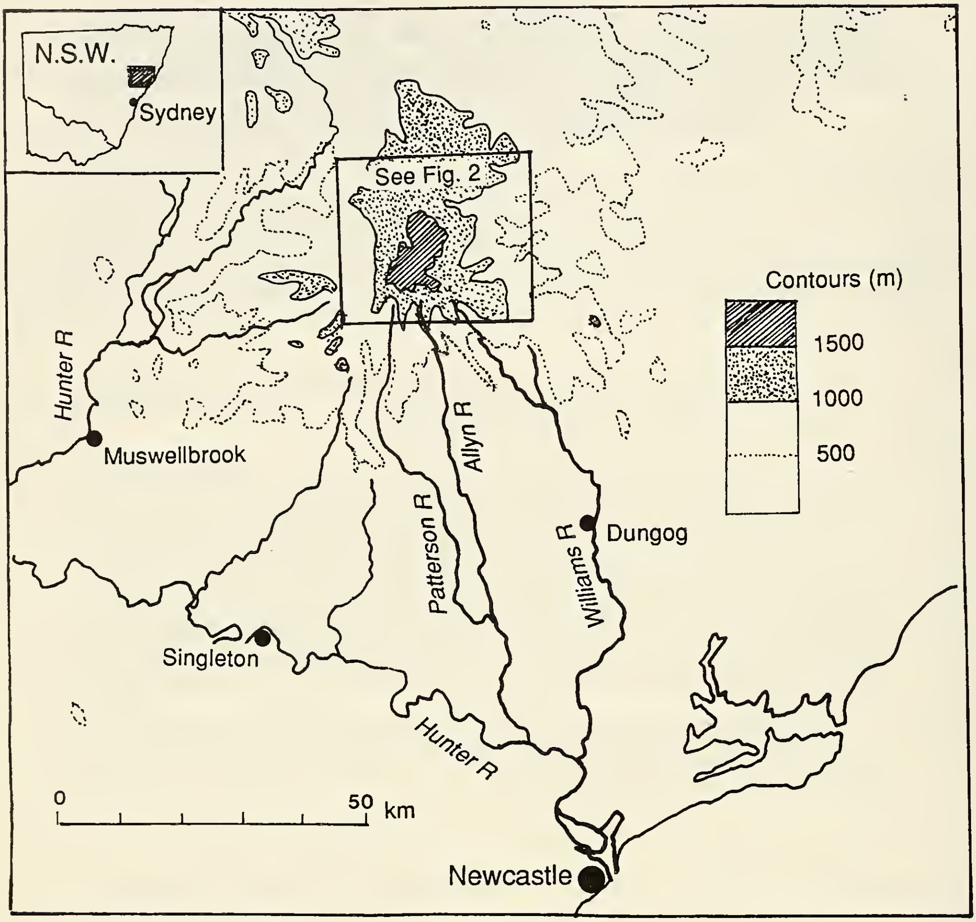


Figure 1. Location of Barrington Tops.

from Burraga Swamp, with an age of probably 12,000 years B.P., adds yet another locality for a more comprehensive picture of the history of the vegetation.

Frazer and Vickery (1937, 1938, 1939) made detailed studies of the vegetation of the Williams and Allyn River regions and Turner (1976) studied an altitudinal transect in rainforest some 3 km to the northwest of Burraga Swamp. These authors note that there are no small individuals of *Nothofagus moorei* within the mature *N. moorei* forests, but coppicing is widespread and may be the normal means of reproduction within the forests. Turner (1976) suggests that *N. moorei* is migrating upwards, and Frazer and Vickery (1938) conclude that *N. moorei* is invading the lower eucalypt forests. This study may provide some evidence about the migration of *N. moorei* during the Holocene.

THE ENVIRONMENT

The Barrington Tops massif is largely Permian granite, folded and faulted Carboniferous and Devonian sediments with an eroded Tertiary basalt capping. The plateau surface is gently undulating and the sides are steeply sloping to the south and

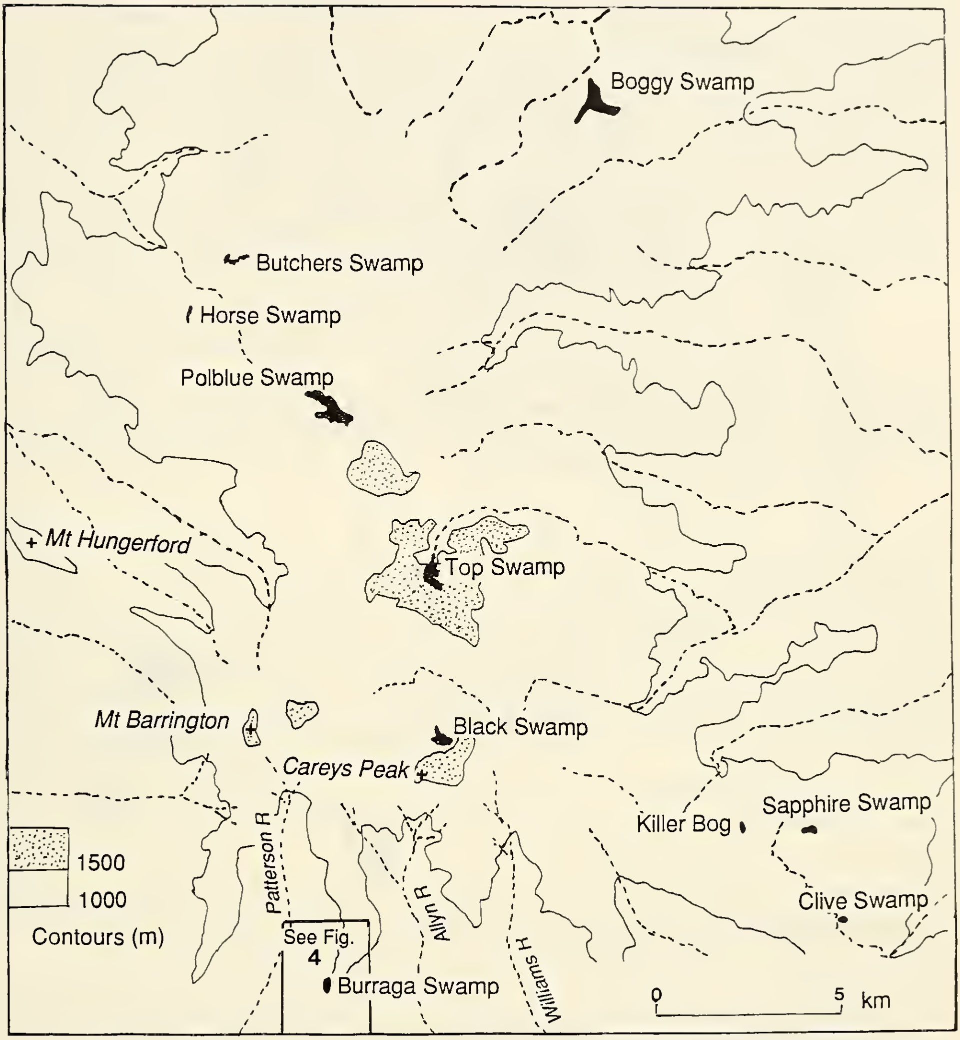


Figure 2. Location of Burraga Swamp in relation to the sites studied by Dodson (1987) and Dodson et al. (1986).

west, but more gently sloping to the north. For an excellent summary of the geomorphology and soils, see Dodson and Myers (1986).

Mt. Lumeah to the north west of Burraga Swamp has a basalt capping and large boulders may be found between the two sites. Smaller boulders and cobbles of basalt may be found throughout the forests.

The region receives both summer rain from the north and winter rain from the south, but in any one year, either climatic type may predominate. The plateau surface receives mean values of over 2,000 mm (Dodson and Myers 1986), and the general precipitation patterns over the region are illustrated in Fig. 3. Mists and fogs may be common in favourable topographic regions and desiccating winds from the west occur mainly in late summer to autumn and in early spring (Frazer and Vickery 1937).

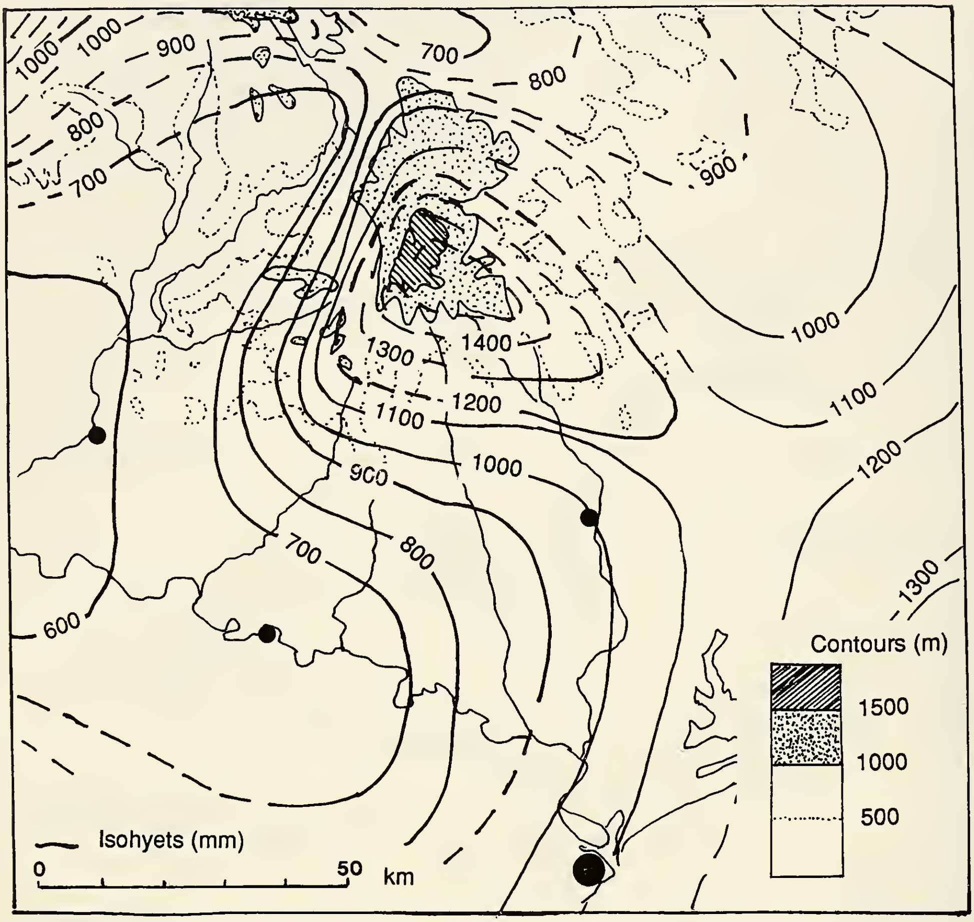


Figure 3. Reconstructed isohyets, from Turner (1981). Broken lines signify uncertainty.

Mean winter minimum temperatures fall below zero and maxima rise to 9–10°C, while summer equivalents of 8–9°C and 22–23°C occur. Maximum temperatures at the base of the plateau are some 5–6°C higher. Snow and frost is common on the plateau (Dodson and Myers 1986).

METHODS

Vegetation

The forest surrounding the swamp was examined in detail and all species encountered were collected and identified. A site 11 km away in riverine subtropical rainforest was studied also, for comparison with the temperate rainforest around the swamp. The vegetation over the swamp was mapped by visual estimation of the percentage cover of the dominant species in 1 m square plots. The author citation of all plant names may be found in Harden (1990–1993).

Stratigraphy of the swamp sediments

Cores along two intersecting transects were studied for stratigraphy. The sediments were described using the Troels-Smith method (Birks and Birks 1980) and seeds were collected for identification. A core from the deepest part of the swamp, approximately in the centre, was sampled at 10 cm intervals for pollen analysis. A Hiller corer was used throughout.

Samples for radiocarbon dating were taken from a hole close to that sampled for pollen analysis. The Department of Main Roads kindly loaned a soil sampling auger for this purpose. Samples were submitted to the Radiocarbon Dating Laboratory, Department of Nuclear and Radiation Chemistry, University of New South Wales.

Modern Pollen Deposition

Samples of moss polsters on the surface of the soil or sediment were collected to assess modern pollen deposition. Collection sites were located on the swamp surface and in the forest surrounding Burraga Swamp. For comparison, Polblue Swamp, some 15 km north, on the plateau surface (Fig. 2) and within subalpine eucalypt forest, was sampled.

Treatment of samples

The carbon content of the sediments was estimated from loss of weight by ignition at 450°C. A subsample of 0.2 gm of sediment was spiked with *Alnus* pollen of 2.76×10^4 grains/mm^3 concentration for the estimation of pollen concentration. The samples were treated with hydrofluoric acid to remove mineral matter, dispersed with 10% sodium hydroxide (heated in a water bath for 10 mins), disaggregated with ultrasonic vibration and sieved through an 85 mesh (0.18 mm) sieve, followed by standard acetolysis (Moore et al. 1991). The residues were dehydrated and mounted in silicone oil. Surface samples were treated in the same way.

Pollen reference samples were treated with acetolysis, dehydrated and mounted in silicone oil.

Pollen analysis

A known volume of a suspension of exotic *Alnus* grains was added to the sediment samples to enable the calculation of the fossil pollen concentration. At least 200 fossil grains, the *Alnus* grains found with the fossils and microscopic charcoal particles were counted. The size of the charcoal particles were mainly 5–65 μm in diameter, i.e. about the same size range as that of spores and pollen. Very few particles larger than 65 μm were encountered. The total concentration of pollen and the concentration of charcoal particles in the sediment were calculated. Pollen concentrations for the most abundant pollen types and percentages for all types were calculated. Individual pollen concentrations are independent of all the others and hence prove a useful aid to the interpretation of the percentages. The total spore and pollen count was used as the pollen sum in the percentage pollen diagrams. The 0.95 confidence limits for the percentages were computed using the methods of Maher (1972). The surface pollen counts are treated in the same way as that of the core.

RESULTS

Vegetation

A map of the general vegetation of the area is presented in Fig. 4. The swamp is within temperate rainforest but there are stands of eucalypt forest within 100 m and sub-

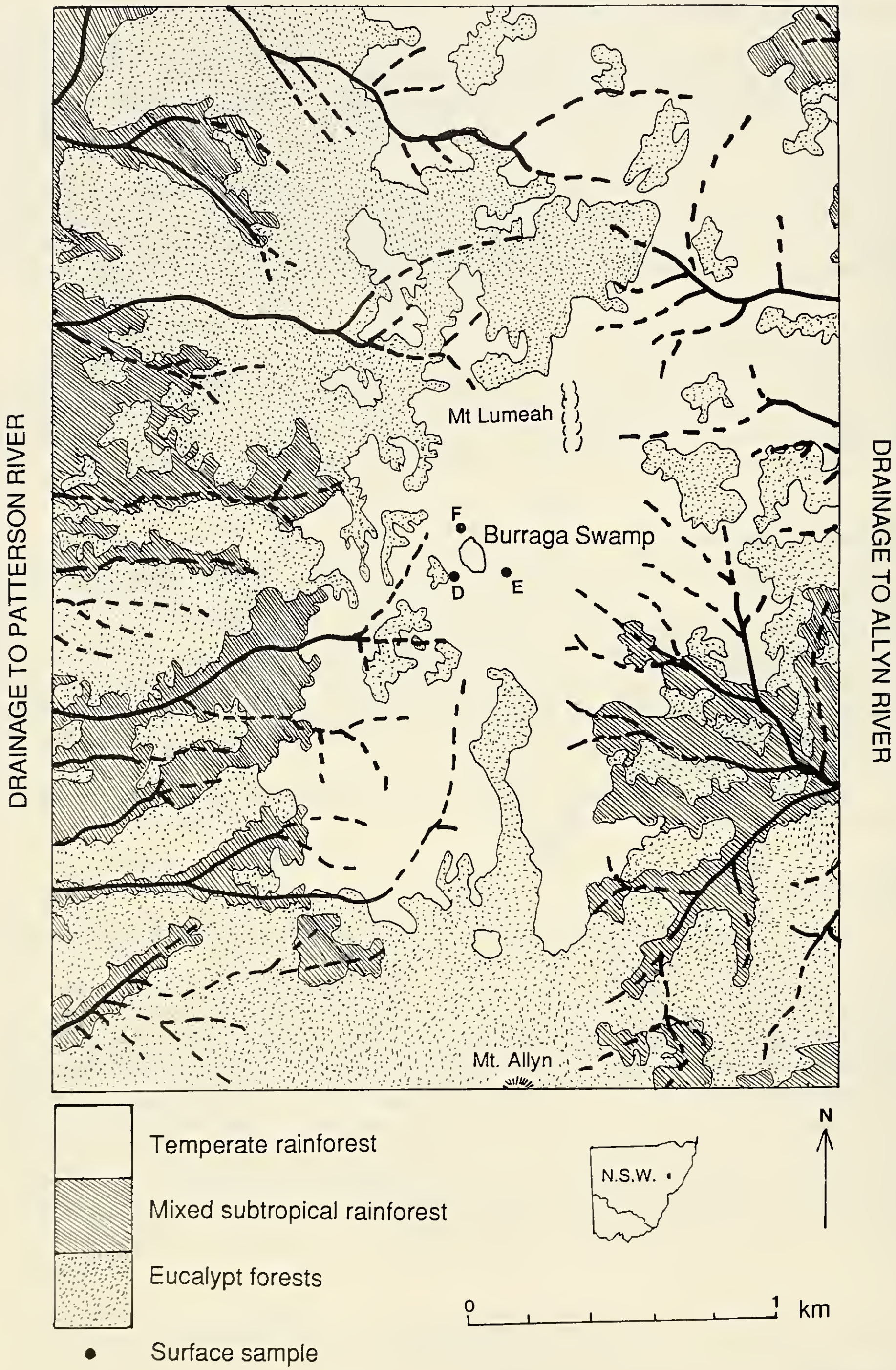


Figure 4. The vegetation of the area around Burraga Swamp, modified from the Boonabilla Management Area Map (Forestry Commission of N.S.W. 1983). For Dominant species, see Table 1. For the vegetation and sites of surface samples on the swamp, see Fig. 5.

tropical rainforest is about a half km away. The chief dominants are shown in Table 1 (Forestry Commission of N.S.W. 1983)

The temperate rainforest around the swamp has a tree stratum 10–30 m tall with a foliage projective cover of more than 70%. This layer has *Nothofagus moorei* dominant. Other species present are *Acmena smithii, Caldcluvia paniculosa, Diospyros australis, Doryphora sassafras, Eucalyptus laevopinea, Orites excelsa, Quintinia sieberi, Rapanea howittiana* and *Schizomeria ovata. Tristaniopsis laurina* and *Tristaniopsis collina* may be found in disturbed areas.

A small tree stratum 2–10 m tall is composed of *Coprosma quadrifida, Solanum* sp, *Hymenanthera dentata* and *Duboisia myoporoides.* The tree fern *Dicksonia antarctica* is usually over 2 m tall. There may be shrubs less than 2 m, viz *Coprosma quadrifida, Rubus rosifolius* and around the swamp, *Rubus hillii* and the introduced stinging nettle, *Urtica urens.*

TABLE 1

Forest types around Burraga Swamp. Modified from the Boonabilla Management Area, Map (Forestry Commission of N.S.W. 1983).

Temperate Rainforest

Dominants:

Nothofagus moorei
Eucalyptus laevopinea
Orites excelsa
Schizomeria ovata

Ferns and vines present

Mixed Subtropical Rainforest

Dominants:

Eucalyptus laevopinea

Variable:

Caldcluvia paniculosa
Diploglottis australis
Elaeocarpus grandis
Orites excelsa
Citronella moorei
Toona ciliata
Schizomeria ovata
Litsea reticulata
Dysoxylum fraserianum
Cinnamomum oliveri
Cryptocarya erythoxylon

Also present:

Tristaniopsis collina
Dendrocnide excelsa

Eucalyptus forests

Main dominants:

Eucalyptus laevopinea
E. campanulata
E. saligna
E. quadrangulata
E. acmenoides
E. canaliculata
E. punctata

Understorey: dry or moist

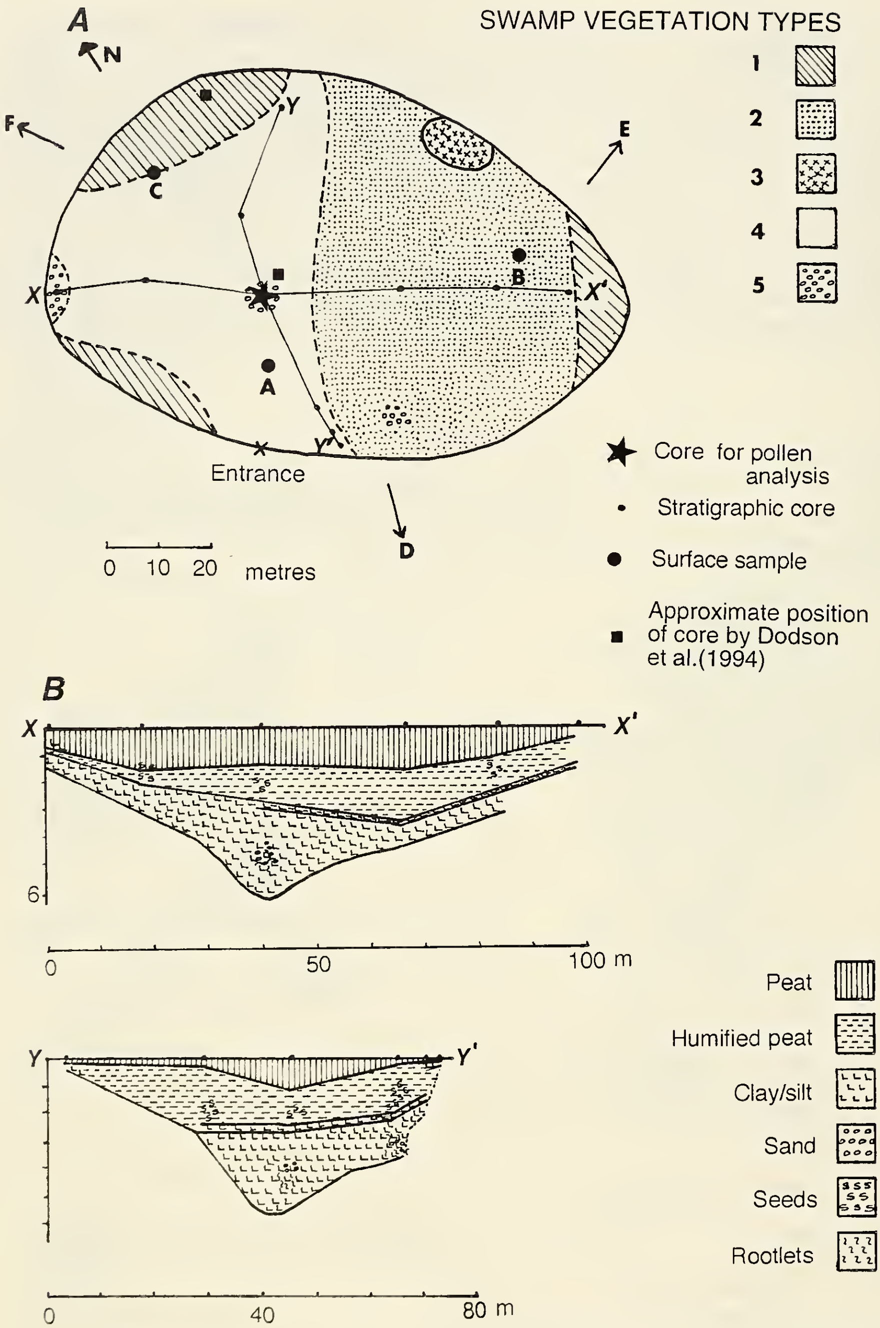


Figure 5. A. Burraga Swamp showing vegetation, core for pollen analysis, swamp surface sample sites and direction of forest surface sample sites. The approximate position of the cores studied by Dodson et al. (1994) are shown. 1). Dense *Phragmites australis* community: 40–50% P. *australis*, 60–50% *Cyperus lucidus*. 2). Patchy *P. australis* community with *P. australis*, *C. lucidus*, *Glyceria australis*, mosses and *Lastreopsis microsora*. Very hummocky. 3). *Glycera australis* community with 70% *G. australis*, 15% *Cyperus lucida*, 10% moss and 5% *L. microsora*. 4). *Glycera australis*, *Phragmites australis* community with 50% of each one and some moss. 5). Mainly bare ground with a moss cover and a little *G. australis*. B. Profiles of the swamp.

Ground-covering plants are found mainly in the higher light intensities of the canopy gaps and are usually herbaceous and less than 1 m tall. *Carex appressa, Hydrocotyle tripartita, Dianella* sp, *Juncus usitatus* and *Lomandra spicata* are found here. Trailing or twining plants include *Morinda jasminoides, Pandorea pandorana, Parsonsia staminea, Polygonum subsessile, Polygonum decipiens, Dioscorea sp.* and *Cayratia clematidea.*

Ferns are common in the ground cover also. The species include *Hymenophyllum flabellatum, Pellaea falcata, Lastreopsis microsora, Hypolepis* sp. and marginal to the forest, *Pteris* sp. The epiphytic ferns *Microsorum diversifolium, Microsorum scandens* and *Arthropteris tenella* are present also.

The swamp vegetation is mapped in Fig. 5. The main dominants are *Phragmites australis, Cyperus lucidus* and *Glyceria australis.* Five communities have been defined and these are shown on Fig. 5.

The species identified from the surface sample sites are found in Table 2 and a list of all species identified in the study area is given in Appendix 1.

TABLE 2

Species identified from the Surface Sample Sites (see Fig. 5.)

Swamp sites

A: *Glyceria australis, Phragmites australis,* mosses

B: Patchy distribution of *Phragmites australis, Cyperus lucidus, Glyceria australis,* mosses and the fern *Lastreopsis microsora.*

C: *Cyperus lucidus, Phragmites australis*

Forest sites

D: Junction of *Eucalyptus laevopinea* and *Nothofagus* forests.
Eucalyptus laevopinea, Nothofagus moorei, Caldcluvia paniculosa, Schizomeria ovata, Orites excelsa, Syzygium australe, Doryphora sassafras, Daphnandra tenipes, ground ferns.

E: South East Forest, Burraga Swamp
Nothofagus moorei, Orites excelsa, Doryphora sassafras, Syzygium australe, Caldcluvia paniculosa, Daphnandra tenipes, Citriobatus sp., *Dicksonia antarctica,* ground and tree creeper ferns. *Hymenanthera dentata, Symplocos* sp., *Cryptocarya* sp.

F: North Side Forest, Burraga swamp
Nothofagus moorei, Caldcluvia paniculosa, Syzygium australe, Schizomeria ovata, Diploglottis australis, ground and tree creeper ferns

Swamp stratigraphy

The location of the transects and cores in the swamp are shown on Fig. 5A. The profiles of the swamp along the transects are shown in Fig. 5B.

There is a root mat at the surface overlying fibrous peat. Seeds, pieces of wood and charcoal fragments may be encountered in the peat. Clayey peat underlies the peat, with a grey clay and silt layer beneath the clayey peat. Thin layers of peat with roots may be encountered in this latter layer. The peat and clay layers thin out towards the edges of the swamp and are thickest in the centre. The stratigraphy of the core sampled for pollen analysis is shown in Fig. 6. The carbon content (Fig. 7) is lower in the clay/silt layer and higher in the peat, as expected.

Seeds collected from the peat were identified as *Eleocharis sphacelata,* cf *Scirpus* sp, *Carex fascicularis* and *Carex brownii* (K. Wilson pers. comm.).

The radiocarbon dates are given in Table 3 and their place in the stratigraphy on

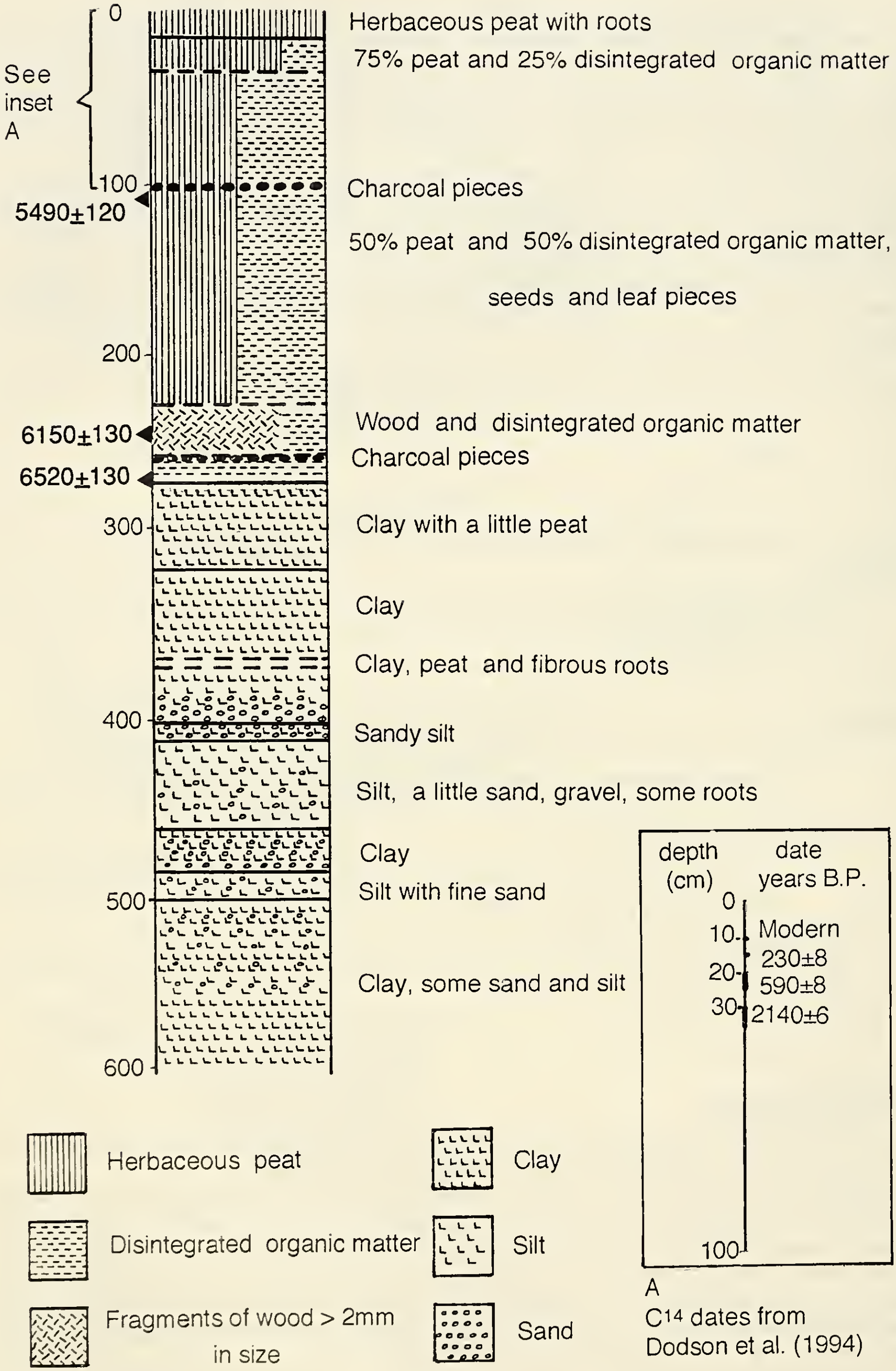


Figure 6. The stratigraphy of the core sampled for pollen analysis. The radiocarbon dates from the core in the centre of the swamp, studied by Dodson et al. (1994), are shown also.

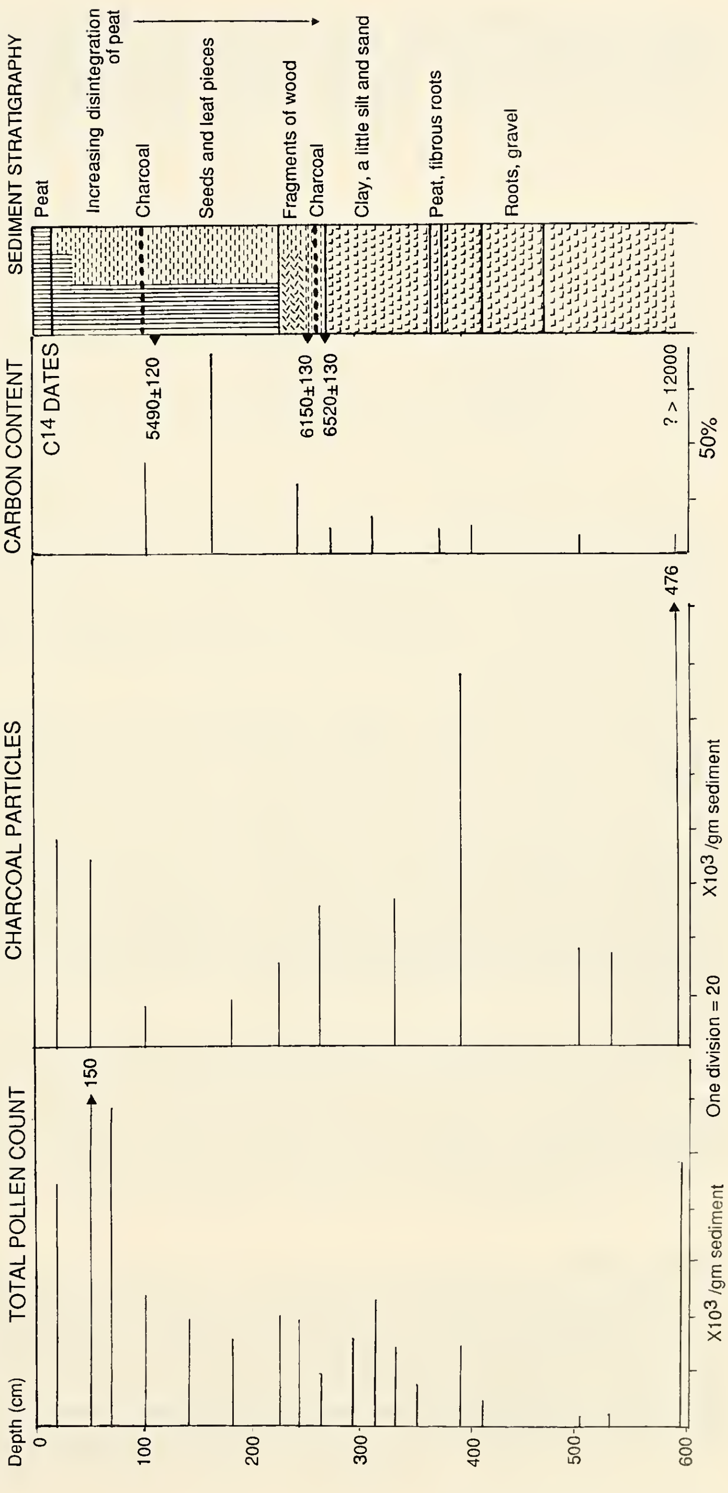


Figure 7. Total pollen concentrations, microscopic charcoal particles and carbon content. The symbols on the sediment column are the same as those for Fig. 6.

Fig. 6. They show that the base of the peat layer is 6,500 years old. The clay contained insufficient carbon for dating, but if the average rate of accumulation of the peat is extrapolated, then the base of the clay would be about 12,000 years old. Other possibilities and the reasons for this assumption are discussed further, below.

TABLE 3

Radiocarbon age of the sediments

Depth (cm)	Reference No.	Age (years BP)
100–110	NSW 345	5490 ± 120
240–250	NSW 348	6150 ± 130
260–270	NSW 347	6520 ± 130

Initially, the swamp was a lake which accumulated clays, washed in from the surrounding slopes. Being an enclosed basin, sediments originated only from erosion of the slopes. Occasionally, some high energy event, such as a rainstorm, transported some sand or gravel into the lake, but such events were uncommon and minor. The thin layers of peaty clay with roots show that the lake had become shallow and the surface was colonised by swamp vegetation for a short time. Throughout its history, the lake was probably never very deep.

At 265 cm, the change of the sediments from clay to organic material shows lake levels had fallen again and the surface was covered with swamp vegetation. This change occurred about 6,500 years ago and the surface has remained vegetated ever since. The substantial amount of wood in the sediments at 220–250 cm suggests that trees, or at least woody shrubs grew on the swamp surface, for there is no evidence of the transport of wood from the forest to this site in the middle of the swamp. Some high values of a small-grained Myrtaceae pollen occur with the wood, hence woody myrtaceous swamp shrubs, which are not present there now, are a possibility. Dodson et al. (1994) identified a substantial amount of *Leptospermum* pollen from the centre of Burraga Swamp, thus woody myrtaceous swamp shrubs have grown at the site. Pieces of leaves and seeds are found throughout the peat. The charcoal layers bear testimony of fires over the surface of the swamp.

The peat accumulated at a rapid rate, approximately 150 cm in 1,000 years, initially. The rate of accumulation after 5,500 years ago has been slower, 110 cm in 5,500 years, assuming that deposition has been continuous to the present, and the surface has not been eroded. The radiocarbon dates from the centre of the swamp core studied by Dodson et al. (1994), where the 15–20 cm level is 230 years old and the 30–35 cm level is 2,140 years old, supports the assumption that there has been no erosion of the surface.

Pollen analysis

There is a high concentration of pollen at the base of the profile (Fig. 7). The 400–590 cm section has a very low pollen concentration and there were too few grains to count from 420–500 cm. The section from 100–400 cm has moderate concentrations, with higher concentrations from 0–100 cm. Charcoal particle values are variable, with higher values in the clay/silt layer and the lower values in the peat. The lowest concentration of charcoal particles, from 100–200 cm depth, coincides with the highest frequencies of *Nothofagus* pollen. A comparison of pollen concentration and percentages (Fig.

8) for the major pollen types show that both methods produce generally parallel patterns, with some minor deviations, especially in the peat. Substantial deviation from essentially parallel trends are seen with Poaceae and *Myriophyllum* in the clay, where the percentages show an inverse relationship, i.e. where Poaceae is high, *Myriophyllum* is low and vice versa, which is not reflected in the pollen concentrations. A similar pattern may be seen in *Nothofagus* above 100 cm, where percentages decrease but concentrations increase.

The pollen diagram for both surface and core samples is shown on Fig. 9. A definition of all the pollen taxa on the diagram with their distribution in the vegetation is given in Appendix 2.

The frequency of *Nothofagus* pollen is low in the clay, increasing from the base of the peat. The level at which values comparable to those of the surface samples are reached, is about 200 cm. The values for Myrtaceae are moderate through most of the profile, with some high values in the peat. The high values all result from increases in the small grain group (Fig. 10), with the *Eucalyptus* content remaining fairly constant, except for the very top. The base of the clay also has a somewhat higher value than the rest of the profile. *Casuarina* pollen is relatively low throughout and is probably the result of long distance dispersal. These three pollen groups would account for most of the tree pollen.

A separate analysis of the Myrtaceae pollen (Fig. 10) identifies three groups: *Eucalyptus/Syzygium, Melaleuca* and a small grain group, size < 14 µm, probably consisting of *Tristaniopsis, Backhousia, Baeckea* and possibly *Acmena* (see Appendix 2). Fig. 10 shows moderate frequencies of *Eucalyptus/Syzygium* at the base of the profile followed by mostly low values upwards and a maximum at the surface. *Melaleuca* is sporadic and low throughout. The small grain group frequencies are low to moderate through most of the profile with occasional high values in the upper part. The high values of total Myrtaceae (Fig. 9) are thus almost entirely due to increases in this small grain group. As discussed above, myrtaceous swamp shrubs, e.g. *Leptospermum* (identified by Dodson and Myers 1986), would fall within this small grain group.

Frequencies of Cyperaceae are moderate to low in the basal clay with higher values in the upper peat. Poaceae, however, shows opposite trends with higher values in the clay, reaching a maximum at 340–370 cm, and lower frequencies in the peat. Fig. 11 shows the analysis of size frequencies of Poaceae from some levels in the profile and suggests that different species are involved. *Myriophyllum* shows variable frequencies, in both clay and peat. The other herbaceous taxa (Fig. 9) have low values, varying only a little through the profile.

The tree fern *Dicksonia* shows low frequencies with the exception of higher values at 280–310 cm, the top of the clay. The other fern spore groups all have low to moderate frequencies throughout, with only small variation.

The pollen spectra may be divided into two major zones, an open, grassy Zone 1, coinciding with the lake phase and clay deposition and a forested Zone 2, coinciding with the swamp phase and peat deposition. Each zone may be further subdivided, as shown on Fig. 9.

<u>Zone 1, 265–600 cm.</u>

Throughout the zone, eucalypts were virtually the only trees. In subzone A, there is an exceptionally high content of *Myriophyllum* and low frequencies of practically every other pollen type. In subzone B, Poaceae and *Myriophyllum* have high values, but in an inverse relationship, i.e when Poaceae is high, *Myriophyllum* is low. The other herbaceous pollen types are low, but some of the fern spore groups may have somewhat higher values. In subzone C, *Dicksonia* increases to a peak at the top of the zone. The herbaceous taxa *Ranunculus* and *Hydrocotyle,* and some of the fern spore groups have higher values also.

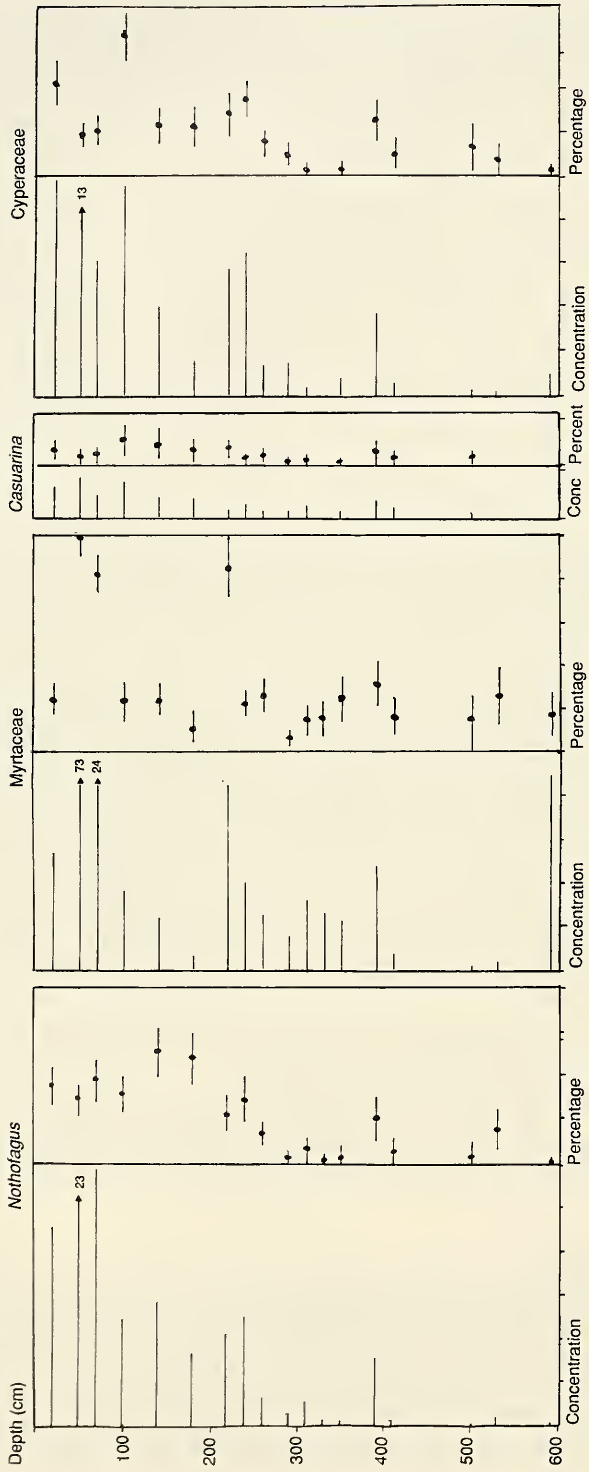
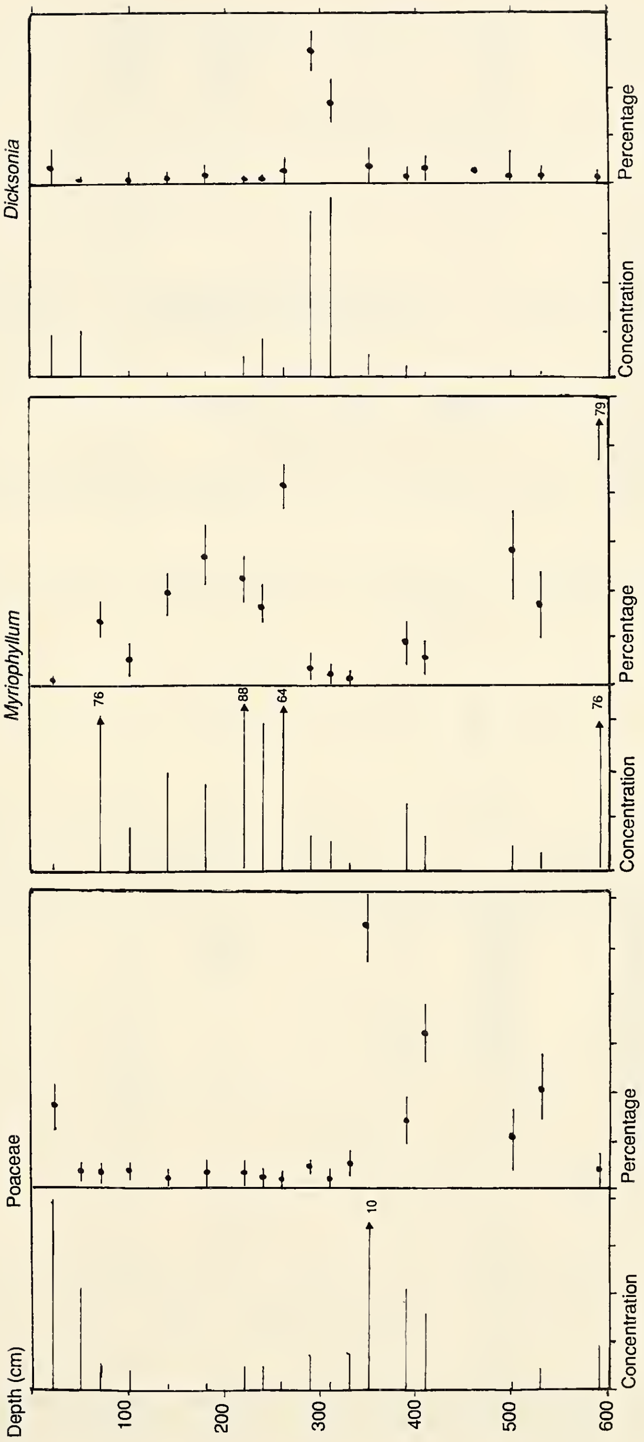


Figure 8.
A comparison of pollen concentrations and percentages. Scales: Pollen concentrations, one division=2×10^3 grains/gm. Percentages, one division=10% of total spore and pollen count.


Dicksonia
Percentage
Concentration
Myriophyllum
79
76
88
64
76
Percentage
Concentration
Poaceae
10
Percentage
Concentration
Depth (cm)
100
200
300
400
500
600

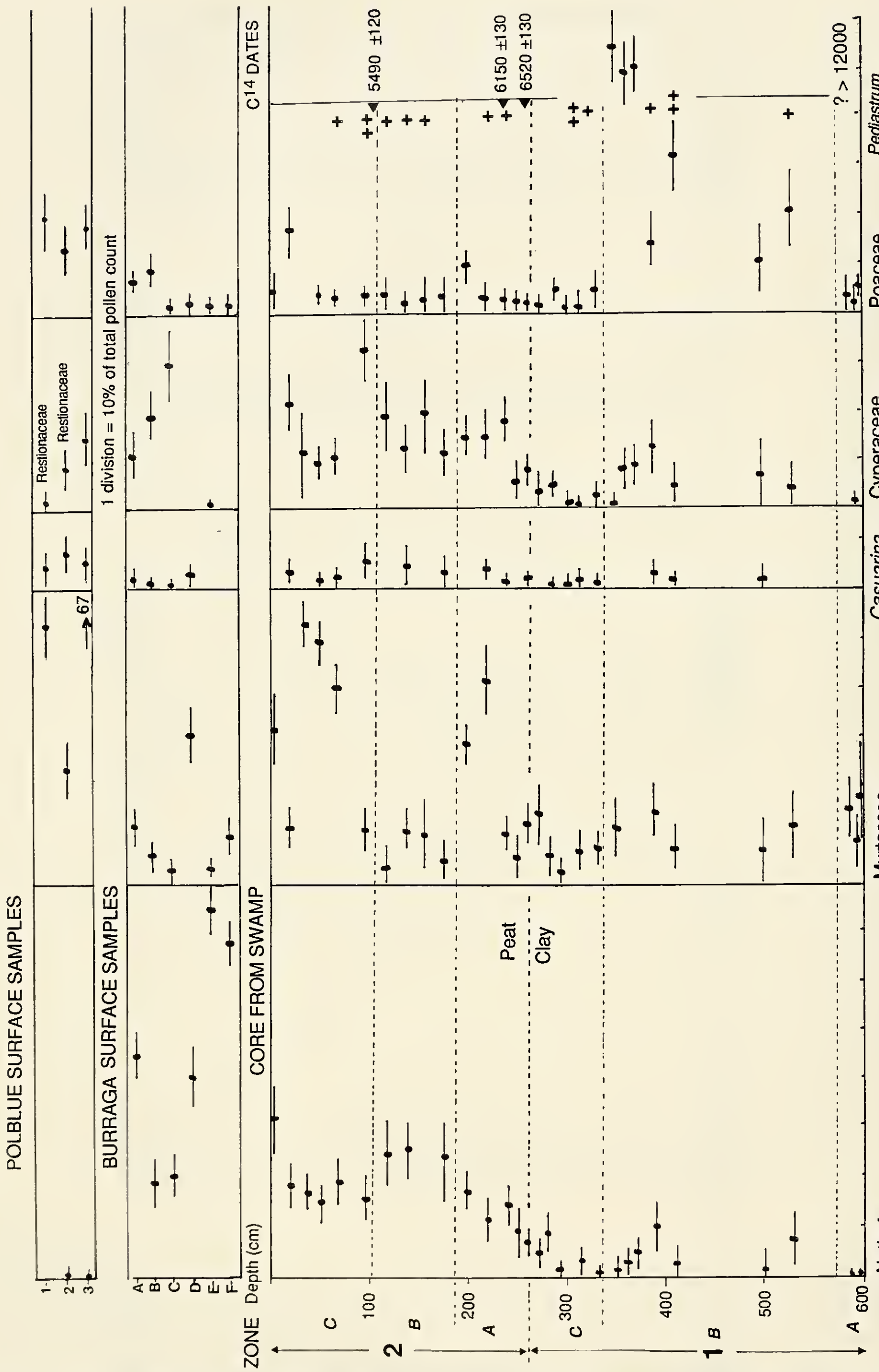
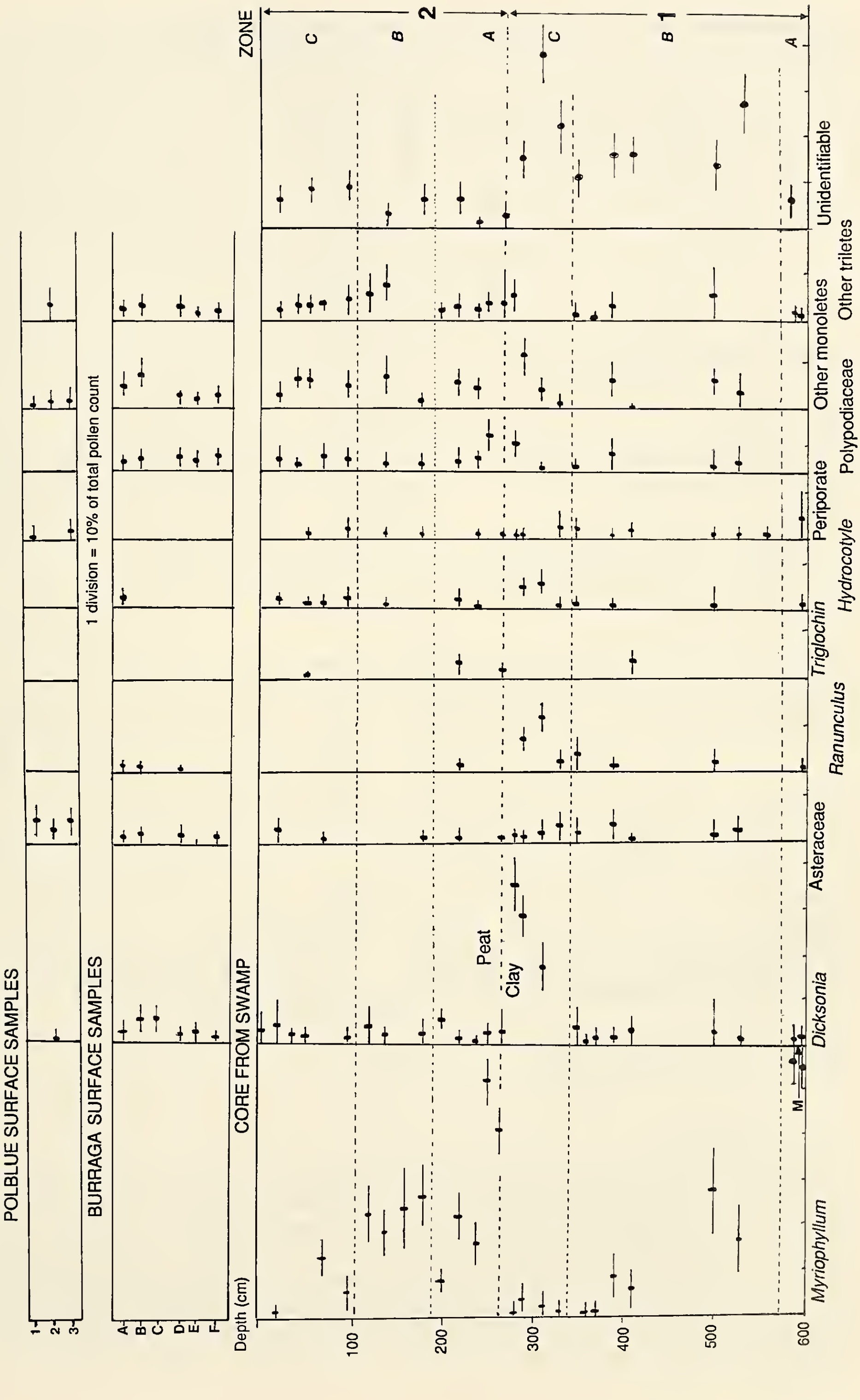


Figure 9. Pollen Diagram. The Polblue surface samples are as follows: 1, Eucalypt forest. 2, *Sphagnum* swamp. 3. Eucalypt forest. For the position of the Burraga surface samples, see Fig 5. For *Pediastrum*, + = present and ++ = abundant. The unidentifiable group records degraded, crumpled and distorted grains. M, The arrow indicates 79% of *Myriophyllum*.


POLBLUE SURFACE SAMPLES
1
2
3
BURRAGA SURFACE SAMPLES
A
B
C
D
E
F
1 division = 10% of total pollen count
CORE FROM SWAMP
Depth (cm)
100
200
300
400
500
600
ZONE
2
1
C
B
A
C
B
A
Peat
Clay
M
Myriophyllum
Dicksonia
Asteraceae
Ranunculus
Triglochin
Hydrocotyle
Periporate
Polypodiaceae
Other monoletes
Other triletes
Unidentifiable

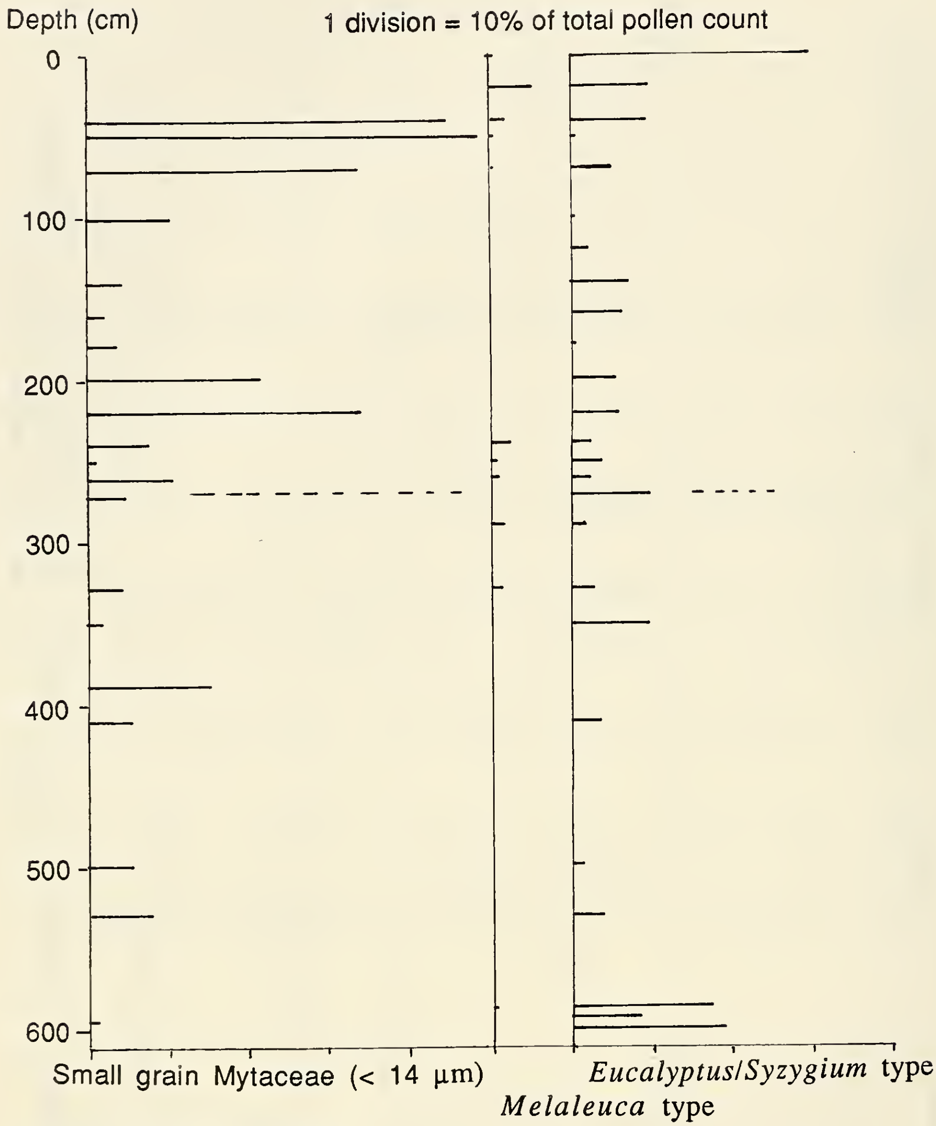


Figure 10. Analysis of Myrtaceae pollen.

Zone 2, 0–265 cm.

The base of the zone coincides with the transition from clay to peat. *Nothofagus* frequencies increase in a transitional subzone (2A), followed by relatively high and stable values (2B) and then a slight fall with a subsequent rise at the very top (2C). Subzone 2A has fluctuating values for Myrtaceae and *Myriophyllum*, whereas subzone 2B has relatively low and stable values for Myrtaceae and high stable values for *Myriophyllum*. Subzone 2C has fluctuating values for Myrtaceae and low values for *Myriophyllum*. Throughout the zone, Cyperaceae has high values, and Poaceae and *Dicksonia* are low.

The small amount of *Nothofagus* pollen in the lake phase (Fig. 9), suggests either long distance transport or a very small stand nearby. *Nothofagus* pollen has a reputation for being over-represented and capable of long distance transport, but in Victoria, only 1–2% of *Nothofagus cunninghamii* pollen disperses more than 70 m from the edge of small stands (K. Harle pers. comm.). In New Zealand, pollen of *Nothofagus menziesii* is under-represented and not as widely distributed when compared with that of the *fusca* species (McKellar 1973). *Nothofagus moorei*, the species of this study, has the same pollen type as *N. cunninghamii* and *N. menziesii*, and our surface samples show its distribution is fairly localised. In view of the evidence about pollen dispersal, *Nothofagus* would have been very minor in the vegetation around Burraga during the lake phase, if present at all. This small amount of pollen may have come from *Nothofagus* growing to the east (Dodson et al. 1986), discussed further below.

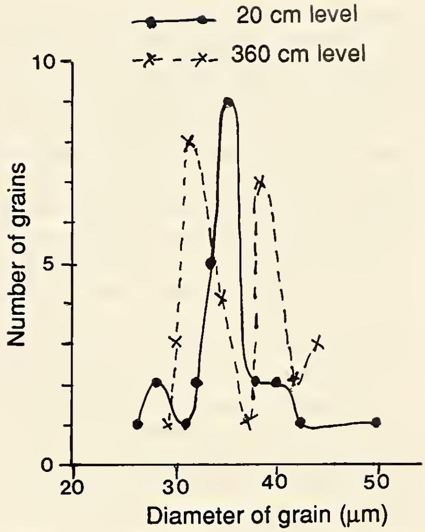


Figure 11. An analysis of the size of Poaceae grains from two levels show that different species are probably involved. There are probably two species represented in the 360 cm level.

Nothofagus increased from about 6,500 years B.P. to a position in the vegetation comparable with that of today at about 6,000 years B.P. There have been fluctuations after that time, but all of the values above the 220 cm level, i.e. about 6,000 years age, fall within those of the surface samples (Fig. 9). The fluctuations would thus fall within the variability seen in the forests today.

The Myrtaceae at the base of the profile is almost entirely *Eucalyptus*. (*Syzygium* is considered unlikely in this pollen spectrum). The low level of eucalypt pollen throughout the profile is lower than that of surface samples (this study and Dodson and Myers 1986), hence eucalypt forests were probably not dominant at any time, at this locality. In the lake phase, prior to 6,500 years B.P., the trees were probably found in sparse clumps occupying suitable habitats. Other myrtaceous taxa were sometimes common, especially in the peat phase, after 6,500 years B.P. Dodson and Myers (1986) characterize the subtropical rainforests by an abundance of *Backhousia* pollen, which would fall within the small grain group of this study. In the peat above 100 cm, when the small grain group of Myrtaceae increases, *Nothofagus* decreases, hence these changes may reflect some increase/decrease of the subtropical rainforests if *Backhousia* is responsible for the large increase in the small grain group. On the other hand, the small grain group may also contain pollen from myrtaceous swamp shrubs, such as *Leptospermum* and *Baeckea*, both of which are found associated with swamps on the Barrington Tops today (Dodson et al. 1986). The wood in the sediments and the identification of *Leptospermum* pollen from Burraga (Dodson et al. 1994) suggests that the swamp shrubs were involved, and the possibility of changes in the subtropical rainforest is only conjectural.

Cyperaceae became prominent once peat started accumulating. The species have changed with time, for the identifications from seeds do not match any of the species growing there today. Poaceae, however, declined once peat started accumulating, suggesting that swamp grasses, such as *Phragmites australis*, were not a major part of the swamp vegetation until recent time. The species of Poaceae have changed during the history of the swamp, as suggested by the grain size analysis (Fig. 11). At times, *Myriophyllum* was abundant in both the lake and peat phases, but this pollen type represents species which grow both in water and on mud (see Appendix 2). The variability of the grains suggests that more than one species was involved.

When the lake first formed, it contained an abundance of *Myriopyllum*. In the subsequent subzone, *Myriopyllum* fluctuated, and when low, there were more Poaceae. There may have been some Poaceae in swamp vegetation around the edge of the lake, but most of the Poaceae would have been growing in the dryland environment. This apparent inverse relationship of Poaceae and *Myriopyllum* may be an artifact of the percentage method where the total must always be 100%. If the lake periodically produced a bloom of *Myriopyllum* while the rest of the vegetation remained the same, the high frequencies of *Myriopyllum* pollen would depress percentages of the other pollen types, and Poaceae, the other pollen type with high percentages, would be depressed the most. Examination of the pollen concentrations (Fig. 8), which do not parallel the frequencies in the clay, suggests the latter explanation.

Dicksonia reaches a peak in the clay, just before the transition to peat, at a time when the tree cover would have been slight, and then remains low in the forested phase. In forests of the Barrington Tops, *Dicksonia antarctica* is most abundant in damp hollows (Turner 1976) and the highest frequencies of spores may reflect high moisture, before the forest cover occupied the site with a consequent rise in evapotranspiration. In Tasmania today, it occurs under canopy gaps and expands rapidly when the rainforest is disturbed (Macphail 1979). It colonizes abandoned fields and forest clearings, and being able to migrate freely, is a logical precursor to rainforest (G.S. Hope pers. comm.). The peak of *Dicksonia* in Burraga Swamp thus heralds the transition to temperate rainforest.

With the change from a lake to swamp environment, there was an initial transition period (subzone 2A) when *Nothofagus* increased and the forests occupied the site. The small grain type of Myrtaceae was abundant near the top of the transitional subzone, and *Myriopyllum,* either growing in water or on mud, was common. Then followed a period (subzone 2B) with maximum *Nothofagus* and less Myrtaceae. In subzone 2C, the percentages of *Nothofagus* suggest a slight decline, but the pollen concentrations are higher. The extremely high levels of Myrtaceae thus depressed the percentages of *Nothofagus*. This subzone has very high total pollen. These changes within the forests, however, are relatively minor.

In summary, during the lake phase, the vegetation around the site was open and grassy with sparse eucalypts, probably restricted to suitable habitats. About 6,500 years ago, peat started accumulating and the *Nothofagus* forests developed. Since about 6,000 years ago, there have been fluctuations in the forests at Burraga but they probably do not exceed the variability seen in the forests of the region today. There is a possibility that woody shrubs were once common in the swamp, whereas they are not present today.

DISCUSSION

During the last glacial period, about 26 to 12.5 thousand years, the climate was drier and very windy, with high evaporation and colder temperatures (Hope 1994). At the height of the last glacial period, the mean temperature was about 9°C lower than those of today in the Snowy Mountains (Galloway 1965). There were very few lakes and rivers trickled intermittently (Dodson 1992). The vegetation was open and herbaceous or shrubby, with few trees (Kershaw 1981, Dodson 1992, Hope 1994). The record in the Burraga Swamp sediments probably starts at the end of this glacial period, at a time when the severe climatic conditions were moderating and surface runoff became sufficient to form the lake.

It is unfortunate that the basal clay of the swamp has not been dated. Extrapolation of the average rate of sedimentation of the upper, dated sediments arrives at an approximate date of 12,000 years, but there is no reason to assume a uniform rate of sedimentation. The dated section of peat shows clearly that the rate of sedimentation was not uniform, with rapid accumulation in the lower half and slower accumulation in the upper part. Lake clays usually accumulate at slower rates than peats. In the study of the swamps at higher altitudes on the Barrington Tops (Dodson 1987), several swamps had a basal clay layer with overlying peat. All of the clays show a slower rate of accumulation, viz., 0.06 to 0.12 mm/yr for clay compared with 0.88 to 2.00 mm/yr for peat. Some of the clays started accumulating before 11,000 years, the oldest dates obtained by Dodson (1987). Most upland sites in southeastern Australia do not extend back beyond 11,000 years, due to gravels and soils underlying swamp and lake sediments (Hope 1994). In view of this evidence, the assumption that the base of the sediments at Burraga are approximately 12,000 years old is not unreasonable.

Changes in the swamp sediments are frequently accompanied by changes in the pollen spectrum. The major change, from Zone 1 to Zone 2 occurs at the clay/peat boundary, hence changes in hydrology occurred at the same time forests developed. The section from 420–500 cm, with too few grains to count, is gravelly and the high energy required to transport gravel is not conducive to pollen sedimentation. The thin peaty layer with roots in the clay at 350 cm depth is accompanied by very high Poaceae values, suggesting that grasses may have been important in this brief interlude of swamp vegetation in the lake phase. About 40 cm above both of the macroscopic charcoal layers in the peat, there is an increase in the pollen concentrations of *Nothofagus*, Myrtaceae and Cyperaceae (see Figs 6 and 8), suggesting that these taxa may have been stimulated by fire. The stimulation by fire of Myrtaceae, most likely *Leptospermum* in this case, is well known. After burning, *Nothofagus* probably regenerated by coppicing, and it may have taken some years before they flowered. Howard (1973) found that trees of *N. cunninghamii* from coppices had both a higher growth rate and an earlier seed production than those from seed. Mass flowering of the *Nothofagus* coppices probably coincided with the peak in the Myrtaceae pollen production.

The history of the swamp sediments at Burraga show similar patterns to the sites on the plateau studied by Dodson (1987). Clay underlies most of the peats and the oldest dates in the clay are more than 11,000 years B.P. The age at which peat starts accumulating is variable. The oldest peat, at Killer Bog, is a thin layer in the clay, dated at 8,230 years B.P. At the other sites, the beginning of peat accumulation starts later, with dates between 4,830 and 740 years B.P., and peat swamps are still forming on the plateau (Dodson 1987).

The pollen diagram shows two major vegetation types: an open grassland with sparse eucalypts, from about 12,000 to 6,500 years, followed by temperate *Nothofagus* forest, from about 6,500 to the present. The pollen analysis of Burraga Swamp may be compared with those studied by Dodson et al. (1986) for the Barrington Tops. Today, the plateau above 1,000 m supports a mosaic of sub-alpine grasslands, montane eucalypt forests, wet eucalypt formations, cool temperate rainforests and wetland communities. The open vegetation prior to 6,500 years at Burraga is similar to that described for about 11,000 years B.P. on the Barrington Tops, except that this latter study found a high Asteraceae (Tubuliflorae) content, whereas this pollen type is minimal at Burraga.

A number of sites on the plateau register *Nothofagus* in the profile (Dodson et al. 1986) and Fig. 12 compares the *Nothofagus* content of Burraga Swamp with that of the others on the Barrington Tops. Black Swamp, the closest to Burraga, has a very similar pattern of *Nothofagus* frequencies. Killer Bog, the most easterly of the sites and with extensive *N. moorei* forests around the site, would have been forested 9,000 years ago. These patterns suggest that the *Nothofagus* forests expanded westward about 6,000 years ago. Boggy Swamp, on the northeast of the plateau, shows a peak at roughly the same time. All the other sites on the higher and more westerly parts of the plateau, where there is little *Nothofagus* today, show relatively little *Nothofagus* pollen which may have been from long distance dispersal, or at most, from small, isolated local stands.

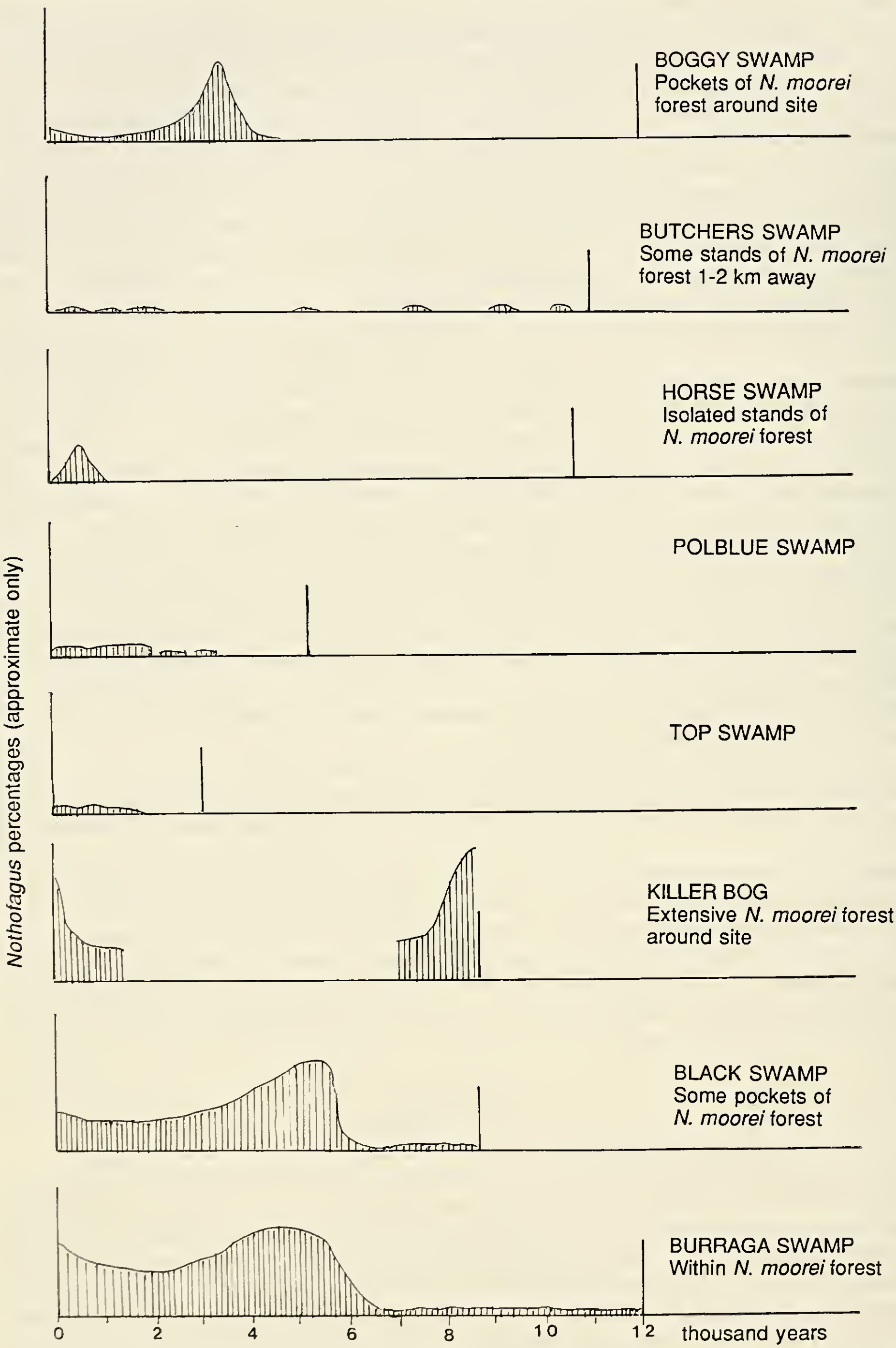


Figure 12. A comparison of the *Nothofagus* content of Burraga Swamp with that of the sites studied by Dodson et al. (1986). All sites are plotted to a uniform time scale and the percentages of *Nothofagus* are approximate only. For location of the sites, see Fig. 2

Dodson et al. (1986) found that all of the vegetation types had become established on the plateau by 9,000 years B.P. There was an expansion of wet eucalypt forests in the west and temperate rainforest in the south and east about 6,500 to 3,500 years, when *Nothofagus* moved into the Burraga site, most likely due to a change in climate. It is thought that an increase in temperatures, perhaps by 1–2°C (Dodson et al. 1994), accompanied by increased summer rainfall from the east and south, allowed this expansion of *Nothofagus*. There followed a contraction of these forests from about 3,500 years, thought to be the result of a slight cooling, and another expansion of the temperate forests about 1,500 years B.P. (Dodson et al. 1986). These latter trends are recorded in Burraga Swamp also.

Dodson et al. (1994) studied two cores with a maximum depth of 35 cm and age of 2,140 years from Burraga Swamp, to assess the effect of human impact. The core from the centre of the swamp registers an appreciable *Leptospermum* content and in the core from the edge, a little of the *Baeckea* type pollen. Relatively little change in the proportions of the temperate and eucalypt vegetation is indicated. Human impact is relatively slight, but there is an increase in the rate of erosion in the catchment at the beginning of the historical period (Dodson et al. 1994).

Ecological studies (Frazer and Vickery 1938, Turner 1976) note the lack of regeneration in mature stands of *Nothofagus moorei* and the occurrence of seedlings and saplings in the adjoining vegetation and conclude that the forest is migrating. Dodson et al. (1986) conclude that *Nothofagus* is expanding its distribution in the west but not in the east. Decreased charcoal input, probably as a result of fire control, may in part account for the small spread in *Nothofagus*. These changes have been going on for over the last 1,000 years (Dodson et al. 1986). In this study, the changes of *Nothofagus* parallel those of Dodson et al. (1986), but they fall within the variability seen in the forests today.

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REFERENCES

Birks, H.J.B. and Birks, H.H. (1980). 'Quaternary Palaeoecology'. (Edward Arnold: London).

Dodson, J.R. (1983). Modern pollen rain in southeastern New South Wales. *Review of Palaeobotany and Palynology* **38**, 249–286.

Dodson, J.R. (1987). Mire development and environmental change, Barrington Tops, New South Wales. *Quaternary Research* **27**, 73–81

Dodson, J.R. (1992). Dynamics of environment and people in the forested crescents of temperate Australia. In 'The Naive Lands. Prehistory and environmental change in Australis and the south-west Pacific' (Ed. J.R. Dodson) pp 115–159 (Longman Cheshire: Melbourne).

Dodson, J.R., Greenwood, P.W. and Jones, R.L. (1986). Holocene forest and wetland vegetation dynamics at Barrington Tops, New South Wales. *Journal of Biogeography* **13**, 561–585.

Dodson, J.R. and Myers, C.A. (1986). Vegetation and modern pollen rain from the Barrington Tops and Upper Hunter River regions of New South Wales. *Australian Journal of Botany* **34**, 293–304.

Dodson, J.R., Roberts, F.K. and De Salis, T.(1994). Palaeoenvironments and human impact at Burraga Swamp in montane rainforest, Barrington Tops National Park, New South Wales, Australia. *Australian Geographer* **25**, 161–169.

Forestry Commission of N.S.W. (1983). Map of the Boonabilla Management area (unpublished).

Frazer, L. and Vickery, J.W. (1937). The ecology of the upper Williams River and Barrington Tops districts. I. Introduction. *Proceedings of the Linnean Society of New South Wales* **62**, 269–283.

Frazer, L. and Vickery, J.W. (1938). The ecology of the upper Williams River and Barrington Tops districts. II. The rainforest formations. *Proceedings of the Linnean Society of New South Wales* **63**, 139–184.

Frazer, L. and Vickery, J.W. (1939). The ecology of the upper Williams River and Barrington Tops districts. III. The Eucalypt forests and general discussion. *Proceedings of the Linnean Society of New South Wales* **64**, 1–33.

Galloway, R.W. (1965). Late Quaternary climate in Australia. *The Journal of Geology* **73**, 603–618.

Harden, G.J. (1990–1993). 'Flora of New South Wales, Vols 1–4'. (New South Wales University Press: Sydney).

Hope, G.S. (1994). Quaternary vegetation. In 'History of the Australian Vegetation: Cretaceous to Recent'. (Ed. R.S. Hill) pp 268–389 (Cambridge University Press, Cambridge).

Howard, T.M. (1973). Studies in the ecology of *Nothofagus cunninghamii* Oerst. I. Natural regeneration on the Mt. Donna Buang Massif, Victoria. *Australian Journal of Botany* **21**, 67–78.

Kershaw, A.P. (1981). Quaternary vegetation and environments. In 'Ecological Biogeography of Australia' (Ed A. Keast) pp 81–102 (W. Junk: The Hague).

Macphail, M.K. (1979). Vegetation and climates in southern Tasmania since the last glaciation. *Quaternary Research* **11**, 306–341.

Maher, L.J. Jr. (1972). Nomograms for computing 0.95 confidence limits of pollen data. *Review of Palaeobotany and Palynology* **13**, 85–93.

McKellar, M.H. (1973). Dispersal of *Nothofagus* pollen in Eastern Otago, South Island, New Zealand. *New Zealand Journal of Botany* **11**, 305–310.

Moore, P.D., Webb, J.A. and Collison, M.E. (1991). 'Pollen Analysis Second Edition". (Blackwell Scientific Publications: London).

Turner, J.C. (1976). An altitudinal transect in rain forest in the Barrington Tops area, New South Wales. *Australian Journal of Ecology* **1**, 155–174.

Turner, J.C. (1981). The distribution of Australian rainforests. In 'Rainforest Conference, May 1981' pp 6–20. (Geographical Society of N.S.W. Conference Papers No. 1: Sydney).

Wakefield, N.A. (1955). 'Ferns of Victoria and Tasmania'. (Field Naturalists Club of Victoria: Melbourne).

APPENDIX 1

Species identified in the study area. Sample sites are: 1 = the swamp surface, 2 = *Nothofagus* forest around the swamp, and 3 = Riverine subtropical forest, 11 km from the swamp. Notes in the species list are: d = disturbed areas, e = edge of forest, l = in light breaks.

SAMPLE SITES:	1	2	3
Mosses			
Campylopus introflexus	+		
Dicronoloma dicarpum	+		
Holomitrium perichaetate		+	
Papillaria sp.		+	
Pteridophytes			
Arthropteris tenella		+	
Dicksonia antarctica		+	
Hymenophyllum sp.		+	
Hypolepis sp.		+	
Lastreopsis microsora	+	+	
Microsorum diversifolium		+	
M. scandens	+	+	
Pellaea falcata		+	
Pteris sp.	+		
Angiosperms			
Apiaceae: *Hydrocotyle tripartita*	+	+	
Apocynaceae: *Parsonsia straminea*		+	
Asteraceae: *Gnaphalium gymnocephalum*	+		
Bignoniaceae: *Pandorea pandorana*		+	
Boraginaceae: *Ehretia* sp.			+
Brassicaceae: *Cardamine hirsuta*	+		
Casuarinaceae: *Casuarina* sp.			+
Cunoniaceae: *Caldcluvia paniculosa*		+d	
Schizomeria ovata		+	
Cyperaceae: *Carex appressa*		+l	
C. inversa	+		
C. lobolepis	+		
Cyperus lucidus	+		
Scirpus inundata	+		
Dioscoreaceae: *Dioscorea* sp.		+	
Ebenaceae: *Diospyros australis*		+	
Escalloniaceae: *Quintinia sieberi*		+	

Euphorbiaceae: *Croton verreauxii*			+
Fabaceae: *Acacia melanoxylon*			+
Cassia sp.			+
Fagaceae: *Nothofagus moorei*		+	
Juncaceae: *Juncus usitasus*		+	
Lauraceae: *Cryptocarya* sp.		+	
Malvaceae: *Hibiscus* sp.			+
Meliaceae: *Synoum glandulosum*			+
Monimiaceae: *Doryphora sassafras*		+	
Moraceae: *Ficus coronata*			+
Myrsinaceae: *Rapanea howittiana*		+	
Myrtaceae: *Acmena smithii*		+	
Backhousia sp.			+
Eucalyptus laevopinea		+	
Syzygium australe		+	+
Tristaniopsis collina		+d	
Onagraceae: *Epilobium* sp.	+		
Orchidaceae	+		
Pittosporaceae: *Citriobatus* sp.		+	
Poaceae: *Agrostis avenacea*	+		
Echinopogon ovatus	+		
Glyceria australis	+		
Microlaena stipoides	+		
Phragmites australis	+		
Polygonaceae: *Polygonum subsessile*		+	
P. decipiens		+	
Proteaceae: *Orites excelsa*		+	
Rosaceae: *Rubus hillii*		+d	
R. rosifolius		+e	
Rubiaceae: *Coprosma quadrifida*		+	
Morinda jasminoides		+	
Rutaceae: *Melicope micrococca*			+
Sapindaceae: *Diploglottis australis*		+	
Scrophulariaceae: *Gratiola peruviana*	+		
Solanaceae: *Duboisia myoporoides*		+	
Solanum sp.		+	
Sterculiaceae: *Commersonia* sp.			+
Symplocaceae: *Symplocos* sp.		+	
Violaceae: *Hymenanthera dentata*		+	
Vitaceae: *Cayratia clematidea*		+	
Xanthorrhoeaceae: *Lomandra spicata*		+	

APPENDIX 2

The species represented by the pollen type.

Pollen type on pollen diagram	Plant species represented by pollen type	Distribution in vegetation
Nothofagus	*N. moorei*	restricted to rainforest
Myrtaceae	all species in Appendix A and any probable	all types of forest
Eucalyptus/ Syzygium type	all *Eucalyptus* spp. and *Syzygium australe*	a few eucalypts scattered in the rainforest, but mostly in mixed rainforest and eucalypt forest. *Syzygium* in rainforest to riverine forest
Small grain Myrtaceae (< 14 μm)	mostly probably *Tristaniopsis*, possibly *Backhousia* sp., maybe *Baeckea gunniana*, some *Acmena smithii*	*Tristaniopsis* in mixed rainforest. *Acmena* in *Nothofagus* forest, *Backhousia* in riverine forest. *Baeckea* not currently in area.
Melaleuca type	similar to *Melaleuca quinquenervia*	not currently in area
Casuarina	probably a mixture of *Casuarina* species	at least 11 km distant from swamp
Poaceae	all species in Appendix A	swamp surface
Cyperaceae	all species in Appendix A	swamp surface and in light breaks in *Nothofagus* forest
Hydrocotyle sp.	probably *Hydrocotyle tripartita*	swamp surface and rainforest
Ranunculus	*Ranunculus* spp.	swamp surface
Triglochin	*Triglochin* spp.	swamp surface
Periporate	*Polyporina granulata* Martin 1973, ?Caryophyllaceae	not sited in region at present
Asteraceae	probably 3 species but mostly *Gnaphalium gymnocephalum*	swamp surface
Myriophyllum spp.	probably *M. pedunculatum, M. varifolium, M. verrucosum*	currently not represented, but *M. pedunculatum* is found in the mud, other two found in water
Dicksonia	*Dicksonia antarctica*	rainforest and tall eucalypt forest
Other trilete	probably a mixture of *Hymenophyllum* sp., *Pellaea falcata, Pteris* sp.	rainforests

Polypodiaceae	probably *Microsorum scandens* and *M. diversifolium*	swamp surface and rainforest
Other Monolete	mostly *Lastreopsis microsora* and *Hypolepis* sp.	swamp surface and rainforest
Unidentifiable	all grains which could not be placed into a taxonomic group owing to its crumpled or broken or degraded state	